C. TECHNICAL CRITERIA FOR THE PREVENTION OF CRITICALITY [1]

1. INTRODUCTION

Atlantic Richfield Hanford Company (ARHCO) Policy Guide 1.6.6, "Criticality Prevention," and Operating Instruction 1.6.6.2, "Criticality Prevention in Process Facilities," present the policy of the Chemical Processing Division with respect to the control of criticality hazards, and delegate the responsibility for specifying safe limits for the design and operation of process facilities to the Manager, Research and Development Department. The purpose of this document is to define the technical criteria to be used in developing the limits within which CPD facilities are to be designed and operated. These criteria are based on the operating experience accumulated from the processing of fissile materials since the year 1944.

The mere existence of a fissile material in quantities greater than a minimum critical mass creates some finite risk that criticality will occur. This risk of criticality can be held to a very low value by imposing restrictions on the manner in which the fissile material is stored or handled. Such controls are to be imposed as needed.

2. POLICY

In all of its activities involving fissile materials, ARHCO shall exercise control such that the probability of a criticality incident is held at the lowest practical level.

3. SPECIFICATIONS

ARHCO Policy Guide 1.6.6 and Operating Instruction 1.6.6.2 require that criticality prevention specifications define the limits within which operating or experimental work may be performed; before issuance, these specifications must be reviewed for technical adequacy by a specialist in criticality calculations and approved by the Manager, Research and Development.

[1] R. E. Tomlinson, "Technical Criteria for the Prevention of Criticality, Chemical Processing Division, ARH-468 REV, April 1971.

3.1 Materials to be Covered

All fissile materials shall be controlled by specifications unless specifically exempted below. Fissile materials are those nuclides capable of sustaining a nuclear chain reaction. Known fissile nuclides are: ^{233}U, ^{235}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am, ^{242}Am, ^{243}Am, ^{244}Cm, ^{247}Cm, ^{244}Cf, and ^{251}Cf.

The following materials are exempt from need for specifications:

- Natural and depleted uranium.
- Fifteen grams of ^{241}Am or any fissile nuclide with atomic number <95.
- Two grams of any fissile nuclide with atomic number ≥ 95.
- Uranium solutions, compounds and metal, if not latticed, enriched to ≤ 1.0 percent ^{235}U or its nuclear equivalent.
- ^{237}Np, ^{238}Pu, ^{241}Am, and ^{244}Cm with H/X ≥ 5 in any amounts.

3.2 Assumptions

In formulating design and operating limits, the responsible process engineer shall consider all pertinent process conditions and failure possibilities. The worst foreseeable combination of fissile material density, diluent composition and distribution, reflection, interaction, and measurement uncertainty must be assumed. Some conditions may be assumed to be incredible if specifically excluded by technical or design considerations. For example, allowances may be made for neutron absorbers, i.e., nitrogen, boron, uranium-238, etc., that will be associated with the fissile material, provided the presence of the absorber can be satisfactorily assured by technical factors or operational control. The use of the assumed conditions by the criticality specialist in reviewing the problem implies his consideration and acceptance of them.

3.3 Technical Review

For specifications that are clearly referable to nationally recognized criticality prevention data, the technical review may be based on agreement between the specification and the data. For specifications based on calculations that cannot be checked by simple reference to recognized data, the review shall be made using two independent calculational methods or a specialist other than the one making the original review will check the calculations.

3.4 Experimental Basis

The specified limits shall be derived from experimental data whenever possible. In the absence of directly applicable experimental measurements, the limits may be based on theoretical calculations, provided the validity of the calculational method has been proven by correlation with experimental data. Attempts shall be made to assign limits of error to both experimental and calculational results.

3.5 Safety Factors

Safety factors must be included in all limits and shall be appropriate for the degree of risk involved. Minimum safety factors may be used when the specified limits are directly referable to experimentally verified values, when operations and design limits can be held within the specified limits with a high degree of confidence, and when an accidental nuclear reaction would produce a minimum of risk to operating personnel or production continuity and no hazard to the public.

The k_{eff} to be used as permissible upper limits for the worst foreseeable conditions is defined below for three levels of confidence in the accuracy of the calculated k_{eff} value:

a. If reliable experimental data exist for closely similar systems and adequate calculational techniques exist for relatively small extrapolation of the data, the k_{eff} of spheres and cylinders shall not exceed 0.98 and the k_{eff} of slabs shall not exceed 0.97.

b. If limited experimental data exist for a similar system and relatively large but reasonable extrapolations are necessary, the calculated k_{eff} of the system shall not exceed 0.95.

c. If no applicable experimental data are available such that calculations must be based on theory derived from experimental data, the calculated k_{eff} of the system shall not exceed 0.90.

Increased safety factors should be used in some conditions as noted below.

3.5.1 Probability of Error

Safety factors shall be proportionate to the probability that the specified criticality prevention limits will be exceeded. For example, it is possible to specify the exclusion of water or equipment dimensions with a high degree of confidence. On the other hand, a possible operating error has a finite probability of being committed at some time in the future.

3.5.2 Risk to Personnel

Sizable and multiple safety factors are desirable when personnel are to be located in the proximity of fissile materials; conversely, when a massive shield is interposed between the fissile material and personnel, a somewhat higher risk of criticality can be tolerated. In this context, a massive shield is defined as at least two feet of ordinary concrete or its attenuation equivalent for the neutrons and gamma rays emitted during a nuclear excursion; the shield and other containment barriers should have sufficient mechanical strength to confine any materials dispersed by the potential reaction.

3.6 Allowance for Emergencies

Recognizing that gross contamination of the environment would create a greater cumulative hazard than would be created by nuclear criticality, the specifications may permit actions involving an increased risk of criticality if necessary to protect a facility from incipient loss of confinement barriers by fire or explosion.[1]

4. SAFETY MECHANISM LIMITS

The several mechanisms whereby criticality may be prevented are listed below in decreasing order of safety assurance. The decision as to which mechanism, or combination of mechanisms, is to be used in a given situation shall represent a balanced judgment, considering the possibility for failure of each mechanism, the degree of risk to personnel or production continuity, and the cost of implementation.

In specifying limits on dimensions, concentrations, or masses, all credible conditions must be considered.

4.1 Geometrically Safe Equipment

Geometrically safe equipment is subcritical by virtue of neutron leakage under all possible conditions of inventory and reflection. To be "geometrically safe" the diameter of a cylinder shall be specified as no more than 2.8 inches, 1.8 inches, or 1.7 inches for handling uranium-235, uranium-233, or plutonium, respectively; similarly, the thickness of a slab shall be

[1] ARHCO Operating Instruction 1.6.6.3, "Criticality Prevention in Fire Fighting," 1971.

specified as no more than 0.5 inch, 0.2 inch, or 0.25 inch, respectively.

These limits are so restrictive that large-scale processing of fissile materials in "safe" equipment would be prohibitively expensive.

4.2 Geometrically Favorable Equipment

Geometrically favorable equipment is subcritical, by virtue of neutron leakage, under the worst foreseeable process conditions. The absence of water flooding or sufficient inventory to sustain a fast neutron reaction may be assumed if these conditions can be maintained with minimal administrative control; such assumptions, if made, must be recorded as a precluded condition in the criticality prevention specification applicable to that facility. The reliance on one dimension of a vessel controlling the reactivity parameters requires that all other dimensions of the vessels either be physically limited by available space or be included in the calculations as infinite dimensions.

The following values are permissible upper limits under the worst foreseeable process conditions, assuming directly applicable criticality data or standards and normal failure potential. If greater uncertainty exists in either the technical basis for the specification or the assurance of control, proportionately greater safety factors as specified in section 3.5 b and c shall be used.

4.2.1 Cylinders

To be "geometrically favorable" the diameter of a cylinder is limited to a maximum value which corresponds to a k_{eff} no greater than 0.98 or to 95 percent of the critical diameter.

4.2.2 Slabs

To be "geometrically favorable" the thickness (the smallest dimension) of a slab is limited to a value which corresponds to a k_{eff} no greater than

0.97 or to 90 percent of the critical slab thickness.

4.2.3 Irregular Shapes

For vessels of unspecified or irregular shape, the permitted volume is no more than 75 percent of the minimum volume that would be critical at optimum concentration.

4.3 Fixed Poisons

When "fixed poisons" are used to prevent nuclear criticality, the equipment must be so constructed that neutron absorbers in the structure prevent criticality under all foreseeable process conditions. Fixed poisons are normally used in a vessel in such a manner as to permit an increase in the size of a critically favorable vessel, the allowable fissile mass, the allowable fissile concentration, or some combination of the three. Periodic inspections shall be specified, as required by the "fixed-poison removal potential of the system," to verify the quantity and location of the poison in the structure. In no case shall inspection intervals exceed one year.

4.4 Nuclear Blanks

A nuclear blank consists of a physically removed section of a process line. Nuclear blanks are used in lines from flushing or utility chemical headers to process equipment when the inadvertent addition of a chemical could cause criticality, such as by precipitation.

4.5 Administrative Controls

When it is not practical to prevent criticality by using favorable geometries or fixed poisons, reliance must be placed either on limitations of mass or concentration, or on the presence of soluble poisons. The process conditions so controlled by operating personnel shall be limited to insure that neutron loss by leakage or absorption will prevent criticality even though any single credible error or omission has been committed. Instruments and/or mechanical devices are provided to assist operating personnel to measure and control the process conditions within prescribed limits.

The following values are permissible upper limits for each mechanism of control, assuming directly applicable criticality data or standards and normal failure potentials. If greater uncertainty exists in either the technical basis for the specification or the assurance of control, proportionately larger safety factors shall be used.

4.5.1 Control by Mass Limits

The quantity of fissile material in a given location is to be limited to an amount less than half that required to sustain a nuclear reaction under any credible conditions of geometry, moderation, and reflection. A double batched condition shall not result in a k_{eff} higher than the applicable limit in Section 3.5 under the worst foreseeable conditions.

In continuous processing systems located behind massive shielding, the quantity of fissile material in a vessel is limited to a maximum of 75 percent of the mass required to cause a criticality in that vessel under the worst credible condition; the k_{eff} of the system under this condition must be within the appropriate limits of 3.5 above. If the continuous processing system is located in an area normally occupied by personnel, the mass in a vessel is limited to less than 50 percent of the mass required for criticality under the worst credible conditions in that vessel.

4.5.2 Control by Concentration Limits - Solutions

The concentration of fissile material dissolved or dispersed in another medium is to be limited such that neutron absorption in the diluent prevents criticality.

The permitted concentration of fissile materials in solution shall not be greater than 50 percent of the minimum critical concentration in that vessel; if the vessel is behind a massive shield, the permitted concentration may be 75 percent of the minimum critical concentration. In neither case shall the k_{eff} at the allowable concentration exceed the applicable value listed in 3.5. In addition, there shall be specified for the vessel a mass limit such that the k_{eff} of the system shall not exceed the applicable value listed in 3.5 under the worst conditions attainable by the inadvertent concentration of the fissile material, as by precipitation, evaporation, etc.

4.5.3 Control by Concentration Limits - Arrays

The dispersal in space of discrete accumulations of fissile materials is controlled with respect to geometry and distance such that the nuclear reactivity of any single subcritical unit is not significantly increased by the mutual exchange of neutrons (interaction) with adjacent units. For a planar or three-dimensional array, the permitted array shall either have a k_{eff} no greater than the applicable value listed in 3.5 for the worst foreseeable conditions or shall be limited in number of units to one-half that calculated to be a critical reflected array. Double batching of a single unit in the array must not exceed the designated k_{eff}.

4.5.4 Control by Soluble Poisons

Neutron absorbing materials are to be in solution with the fissile materials in sufficient concentration to prevent criticality under all foreseeable process conditions. If reliance is placed on the presence of a soluble nonprocess neutron absorber to avoid criticality, the minimum poison concentration shall be specified such that the k_{eff} of the system shall not exceed the applicable value listed in 3.5 for the worst foreseeable conditions. The term "worst foreseeable conditions" must include consideration of mechanisms that might change the poison (absorber) concentration, as well as potential changes in fissile atom concentrations.

Soluble poisons shall not be used as the primary means of precluding criticality unless the system is behind a massive shield. Soluble poisons may be used in unshielded systems as a secondary control to be operative in the event that the primary control mechanism is voided.

5. <u>FIRE FIGHTING</u>

In areas containing fissile materials, the requirements of ARHCO Operating Instruction, 1.6.6.3, "Criticality Prevention in Fire Fighting," shall be considered in all criticality prevention requirements. For example, when specific fire fighting systems (such as automatic sprinkler systems or fire fog) are allowed, the system shall be limited by design such that the addition of the fire fighting media will not permit criticality via increased moderation, reflection, dilution, etc.